MANUSCRIPT 3

SALT CREEK AMMONIA MODELING

CITY OF LINCOLN, NEBRASKA
SALT CREEK WATER QUALITY STUDIES

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SALT CREEK AMMONIA MODELING

Key Findings

The following are Key Findings from the Salt Creek ammonia modeling which highlights the main points and conclusions. Extensive detail on the Salt Creek ammonia modeling set-up, final results and final conclusions are also presented within this Manuscript.

- Simulation modeling and regression modeling were conducted on Salt Creek to predict 30-day average (chronic) historic total ammonia concentrations in Salt Creek below the City's two wastewater treatment plants at corresponding bio-assessment Sites BSS04 (approximately 10,000 feet downstream of the Theresa St. WWTP) and BSS08 (approximately 4,600 feet downstream of the Northeast WWTP).

- Simulation modeling incorporated daily Salt Creek flows and daily wastewater treatment plant flows and ammonia concentrations for a six-year period. The modeling effort also incorporated an ammonia loss factor to account for ammonia changes over distance.

- The accuracy of the model to predict daily total ammonia concentrations was quantified by developing 95 percent confidence intervals. Confidence intervals for total ammonia at the two key biological sites were 1.55 mg N/L (BSS04) and 1.88 mg N/L (BSS08).

- The maximum 30-day average total ammonia concentration in Salt Creek at Sites BSS04 and BSS08 were selected for the derivation of bio-assessment–based, site-specific chronic ammonia criteria. The 30-day maximum average total ammonia values were 4.84 mg N/L and 5.62 mg N/L at Sites BSS04 and BSS08, respectively.

1.0 INTRODUCTION AND PURPOSE

To predict historic and future Salt Creek ammonia concentrations below the City of Lincoln (City) Theresa Street and Northeast wastewater treatment plants (WWTP's) two predictive tools were developed and compared. First, simulation modeling, through simple mass balance, was evaluated based on daily background Salt Creek conditions and WWTP conditions and an ammonia loss term. Second, a regression model was developed based on WWTP characteristics and in-stream ammonia at set locations in Salt Creek. Both methods of ammonia estimation can be used to determine historic 30-day average (chronic duration) ammonia concentrations prior to each Salt Creek bio-assessment at "key" locations in Salt Creek. Both methods can also be used to predict future Salt Creek ammonia concentrations, which will allow the City to determine compliance with seasonal site-specific in-stream ammonia criteria. Each method is discussed below.

2.0 SIMULATION MODELING

Simulation modeling was completed which incorporates a simple mass-balance approach combined with an ammonia loss term to calculate 30-day average ammonia concentrations at several key locations in Salt Creek and to predict future ammonia concentrations for compliance purposes. The mass balance was developed using daily Salt Creek background flow (above the Theresa St. WWTP) and seasonal ammonia concentrations along with daily average discharge characteristics of the Theresa Street and Northeast WWTP's. The following sub-sections briefly describe: data utilized in modeling; model set-up; key ammonia simulation points along Salt Creek; development of confidence intervals; and final results of model runs.

2.1 Selection of Modeling Data

The primary data, and their source, utilized in the mass balance simulation model are as follows:

- Daily flow for Salt Creek at 27th Street (USGS Station #06803500) and Little Salt Creek (USGS Station #06803510) from October 1, 1993 through November 29, 1999.
- Average daily discharge and ammonia for the Theresa Street and Northeast WWTPs from October 1, 1993 through November 29, 1999.
- United States Geological Survey seepage data (inflow) between the Theresa Street WWTP and Northeast WWTP - 4.8 cfs.
- Seasonal Salt Creek background ammonia concentrations – summer value of 0.09 mg/L and winter value of 0.41 mg/L. (Since daily background ammonia concentrations are not available seasonal values were defined by the Nebraska Department of Environmental Quality (NDEQ) based on historic City and NDEQ collected data).
- Salt Creek water temperature data – two options were evaluated:

    1) Salt Creek water temperature developed from an air/water temperature regression. Air temperature data were from the High Plains Climatic Center (University of Nebraska East Campus site) from 1994 through 1999.

    2) Eco-Region water temperature data obtained from the Low Plains Eco-Region for the period from 1965 to 1999. The data are a compilation of temperature measurements collected in streams of similar size and geographic region as Salt Creek.

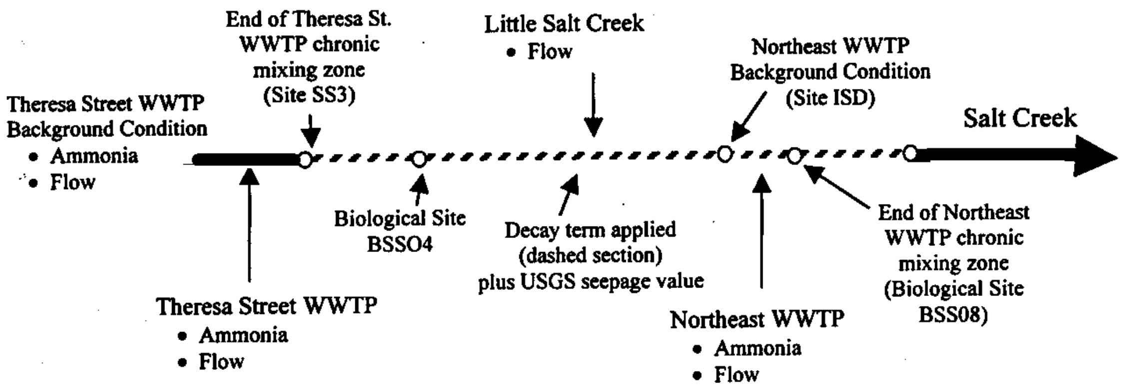
Since flows measured in Salt Creek at 27th Street (USGS Station #06803500) includes effluent flow contributions from the Theresa Street WWTP, daily Theresa Street discharge flows were subtracted from daily 27th Street flow gage values to obtain a "true" background flow rates above the discharge.

2.2 Model Setup

Presented below on Figure 3-1 is a schematic of Salt Creek showing data input points, model features, and key ammonia prediction sites in Salt Creek. Model runs were performed on Salt

Creek from the Theresa Street WWTP discharge point to the end of the chronic mixing zone downstream of the Northeast WWTP, a distance of approximately 7.2 miles.

Figure 3-1. Salt Creek Schematic



There are two primary calculations used in the simulation model. One is the simple mass balance and the second is a loss term. The simple mass balance equation, which combines in-stream conditions and WWTP conditions, is illustrated as Equation 3-1, below

Equation 3-1

$$NH4_{(Background)} * flow_{Background} + NH4_{(WWTP)} * flow_{(WWTP)} = NH4_{(mixed)} * flow_{(Background+WWTP)}$$

2.3 Ammonia Loss

The second primary calculation is the ammonia loss term which is applied along the modeled stream segment to account for ammonia loss between WWTPs and to determine background ammonia above the Northeast WWTP. The loss calculation, which is temperature adjusted, is shown as Equations 3-2 and 3-3, below.

Equation 3-2

$$C_t = C_0 * e^{(-k_T t)}$$

Equation 3-3

$$k_T = k_{20} * \Theta^{(T-20)}$$

where: C_t is the ammonia concentration at time t
C_0 is the initial ammonia concentration at time 0
k_T is the ammonia loss constant at temperature T degrees Celsius
t is time in days, k_{20} is the ammonia loss coefficient at 20 degrees Celsius
Θ is the temperature correction coefficient, equal to 1.1.

The first order temperature dependent loss term was incorporated into the model to account for natural decreases in ammonia along the modeled stream segments from such processes as nitrification and settling. A flow to velocity regression at site SS3, developed using data collected during Salt Creek *in situ* testing (September 20 through October 21, 1999) was used to calculate daily travel times used in the loss term. A loss coefficient of 2.8 day^{-1} was initially used based on previous work performed by the City and utilized by NDEQ. During the calibration process, the loss coefficient was revised to 1.6 day^{-1} to produce a "best fit" for the model as discussed below.

Since Salt Creek water temperature data are not available for each month, two sources of temperature data were evaluated. The first source was monthly Salt Creek water temperatures based on an air/water temperature regression. Air temperature data were from the High Plains Climatic Center (University of Nebraska East Campus site) from 1994 through 1999. Salt Creek water temperatures were from June 1994 through October 1999. The regression equation is shown as Equation 3-4.

Equation 3-4

$$WaterTemp(C) = 0.265 * AirTemp(F) + 0.5357$$

Calculated monthly water temperatures based on the air/water temperature regression are shown in Table 3-1.

Table 3-1 Calculated Average Monthly Salt Creek Water Temperatures

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (Celsius)	6.5	8.9	11.5	13.8	16.8	20.0	21.1	20.6	18.4	15.5	11.2	8.3

The second source was monthly Eco-Region water temperature values from Low Plains Eco Region data for the period of 1995 through 1999, which were obtained from NDEQ. The data are a compilation of temperature measurements collected in streams of similar size and geographic region as Salt Creek.

Eco-Region temperature values are shown in Table 3-2.

Table 3-2 Low-Plains Eco-Region Monthly Water Temperatures

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (Celsius)	0	0	3.5	11.5	17.5	23	25.5	23.5	18	12	4	0.35

After discussions with the NDEQ regarding what water temperature values are appropriate for ammonia modeling NDEQ recommended using the monthly Eco-Region temperature values. Based on this recommendation, monthly water temperatures shown in Table 3-2 above were used in the temperature dependent ammonia loss term.

2.4 Key Ammonia Simulation Points

Four key locations in Salt Creek were chosen as ammonia simulation points. These sites correspond to historic Salt Creek chemical and/or biological sample sites below the Theresa Street and Northeast WWTP's. The purpose and location of each of the four simulation points is summarized in Table 3-3 and can be referenced back to Figure 3-1, above.

Table 3-3 Summary of Ammonia Simulation Points

Site Name	Location	Purpose of Simulation Point
SS3	0.45 miles downstream of Theresa Street WWTP discharge	Point of compliance for Theresa Street WWTP (end of chronic mixing zone)
BSSO4	1.71 miles downstream of Theresa Street WWTP discharge	Simulate in-stream ammonia concentrations at historic biological monitoring site BSS04
ISD	6.26 miles downstream of Theresa Street WWTP discharge and 0.1 mile upstream of the Northeast WWTP discharge	Represents background conditions upstream of Northeast WWTP
BSS08	0.95 mile downstream of the Northeast WWTP discharge	Point of compliance for Northeast WWTP (end of chronic mixing zone) Simulate in-stream ammonia concentrations at historic biological monitoring site BSS08

2.5 Simulation Model Performance

For each of the four Salt Creek ammonia simulation sites, predicted average daily ammonia concentrations were calculated for the period of October 1, 1993 through November 29, 1999. To estimate the fit of the predicted ammonia values to actual in-stream conditions, available Salt Creek measured ammonia concentrations, at the same simulation sites, were compared to the predicted values (Attachment 3-A and Attachment 3-B). For the modeled period, there were 64 actual Salt Creek ammonia measurements from sites SS3, ISD and BSS08 and 34 measurements from site BSS04. For site BSSO4 one outlying data pair was eliminated from the paired data set, because it did not fall within the typical historical measured concentrations. It should be noted that the simulation model predicts average daily ammonia concentrations, but actual measured Salt Creek values are grab or flow-weighted composite samples collected once during the day, and may not fully represent average daily conditions. A comparison of all predicted versus measured Salt Creek ammonia values, using an ammonia loss coefficient of K =2.8 day^{-1}, is shown on Figures 3-2 through 3-5.

Figure 3-2 Measured and Predicted Ammonia at Site SS3

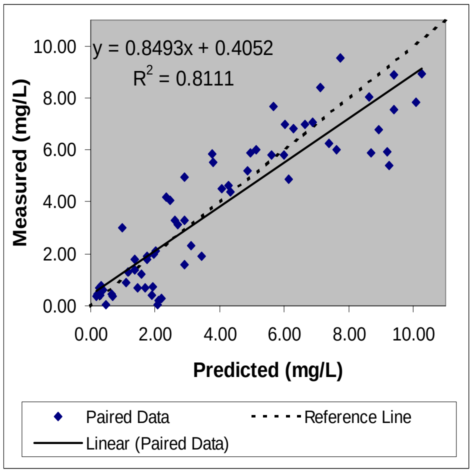


Figure 3-3 Measured and Predicted Ammonia at Site BSS04

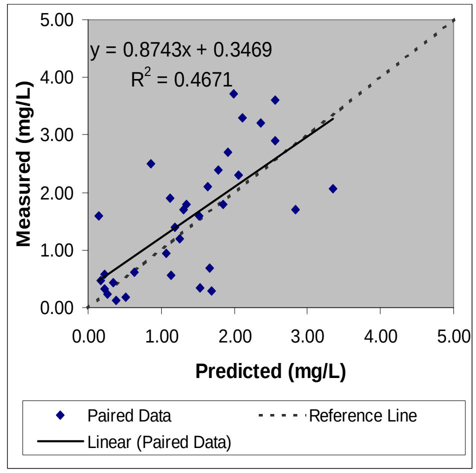


Figure 3-4 Measured and Predicted Ammonia at Site ISD

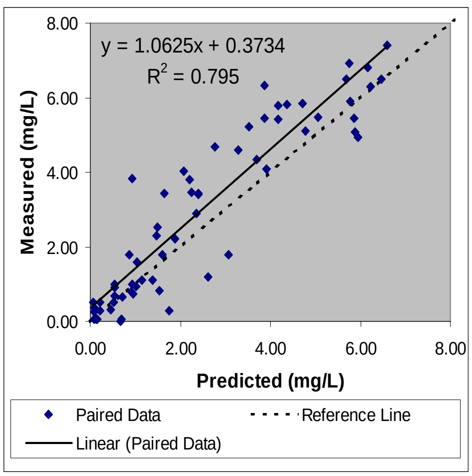
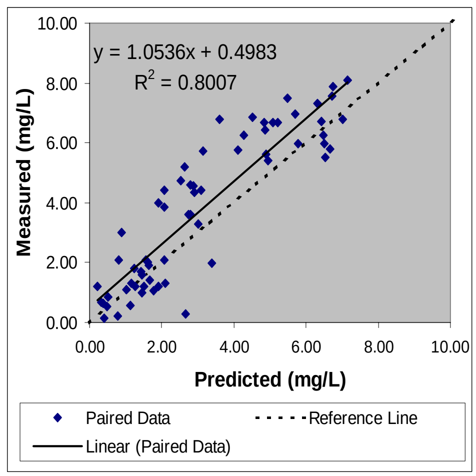


Figure 3-5 Measured and Predicted Ammonia at Site BSS08



On Figures 3-2 through 3-5, the dashed line indicates a reference line where measured and predicted values would be equal to each other. The solid "paired data" line is a linear regression line that best fits the actual slope of the measured and predicted data. Where the best fit line falls above the reference line, the ammonia model predicts lower ammonia concentrations than that actually measured in stream value. Conversely, where the best fit line falls below the reference line, the ammonia model over predicts.

In addition to comparing measured and predicted ammonia concentrations, a comparison of the magnitude and sign of the forecast errors (predicted minus measured) versus the measured value was performed, as shown on Figures 3-6 through 3-9. The purpose of this comparison is to evaluate whether the sign and magnitude of the forecast error is a factor of the magnitude of the measured concentrations.

Figure 3-6. Forecast Error and Measured Ammonia at Site SS3

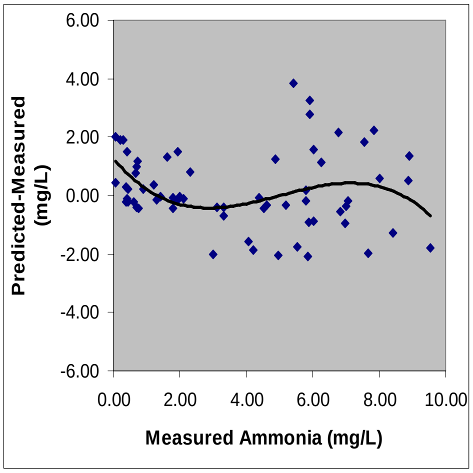


Figure 3-7. Forecast Error and Measured Ammonia at Site BSSO4

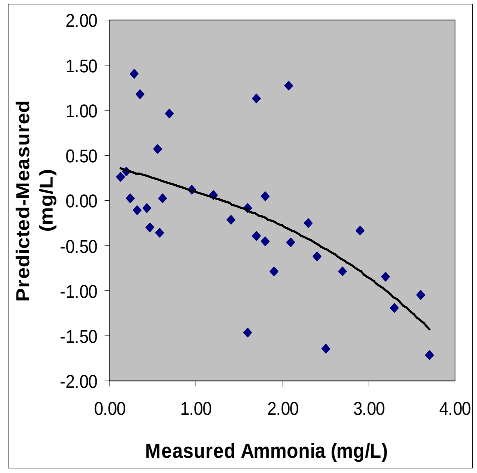


Figure 3-8. Forecast Error and Measured Ammonia at Site ISD

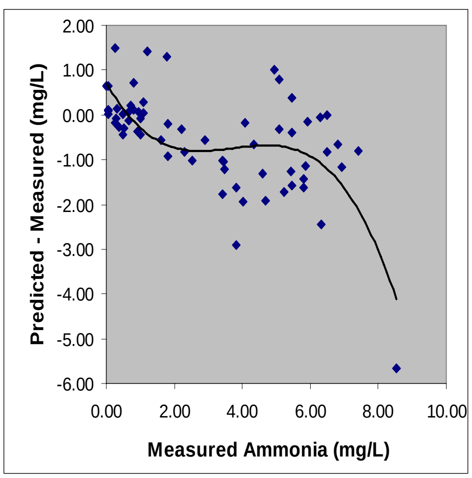
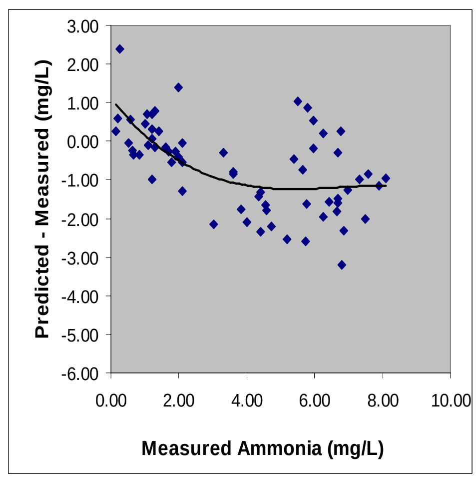


Figure 3-9. Forecast Error and Measured Ammonia at Site BSS08



The solid line on Figures 3-6 through 3-9 is a third-order polynomial fit of the data. If the solid line falls with an increase in measured concentrations, then the forecast error is becoming more negative at higher ammonia concentrations. Conversely, if the solid line rises with increased measured concentrations then the forecast is becoming more positive. In addition, if the data points have a tendency to "fan out" with respect to the solid line as the measured concentration increases, then the precision of the model is decreasing with an increase in measured concentrations.

Figures 3-2 through 3-9 indicate that there is a relatively good correlation (R^2 values for the linear regressions range from 0.46 to 0.84) between the predicted and measured ammonia concentrations using the initial loss coefficient (k=2.8 day^{-1}). However, for sites ISD and BSS08 there appears to be a tendency for the model to under-predict (slopes greater than 1 on Figures 3-3 and 3-5). In addition, this under-prediction tends to increase with the magnitude of the measured value (downward sloping trend-lines on Figures 3-7 through 3-9). For these three sites, the simulation model tends to over-predict ammonia concentrations at lower concentrations, less than 2.0 mg/L, and underestimate at higher measured ammonia concentrations, greater than 6.0 mg/L. Figures 3-6 through 3-9 also show that the scatter of the data around the solid line becomes greater at higher measured values, indicating a decrease in precision of the simulation model as the measured concentration increases.

2.6 Model Calibration

The tendency of the model to under-predict daily ammonia concentrations was addressed by decreasing the ammonia loss coefficient from 2.8 to 1.6 day^{-1}. Figures 3-10 through 3-13 show that reducing the loss coefficient minimizes the negative bias (bringing the slopes closer to 1). This change was especially apparent in sites ISD and BSS08, since travel time is greater at these sites, thus the ammonia loss term has a greater impact on these predicted values. Calibrated model results are presented in Figures 3-10 through 3-13 below.

Figure 3-10. Calibrated Measured & Predicted Ammonia for Site SS3

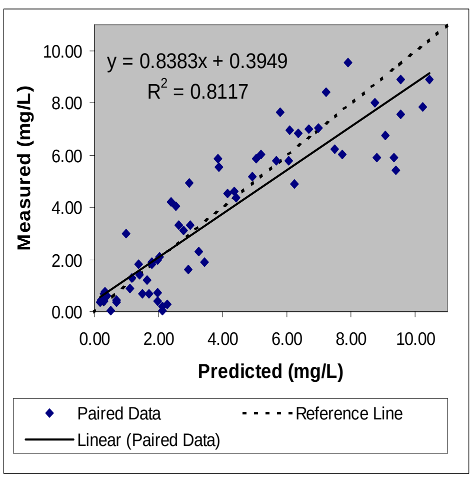


Figure 3-11. Calibrated Measured & Predicted Ammonia at Site BSS04

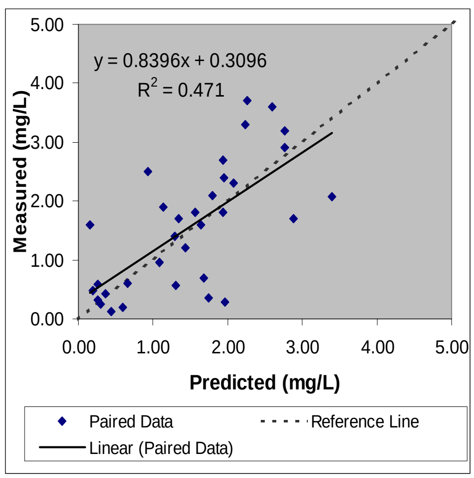


Figure 3-12. Calibrated Measured & Predicted Ammonia for Site ISD

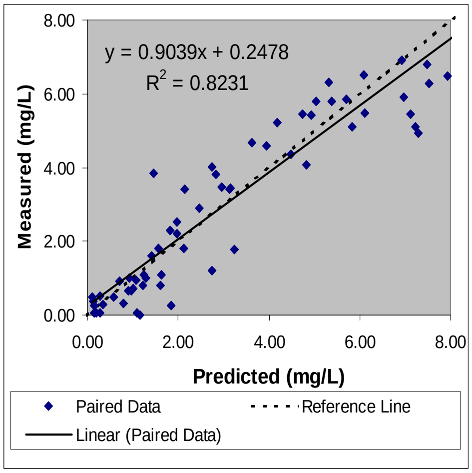
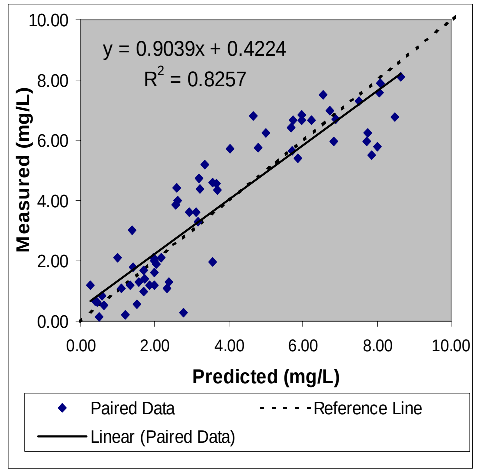


Figure 3-13. Calibrated Measured & Predicted Ammonia at Site BSS08



On Figures 3-10 through 3-13, the best-fit line of the data now falls very close to the reference line (a slope of 1.0). This indicates that for a wide range of measured data, the model is able to accurately predict ammonia concentrations.

2.7 Confidence Intervals

For each ammonia simulation site in Salt Creek, the precision of the model to predict daily ammonia concentration was quantified by developing 95 percent confidence intervals. Two methods were used to determine confidence intervals for each site: Root Mean Square Error (RMSE), which is based on the absolute magnitudes of the difference between the measured and predicted data; and Standard Error (SE), which is based on a linear regression between the two data sets. For both methods, it was assumed that the error was normally distributed and that a 95 percent confidence interval is equal to ± 1.96∗ (SE or RMSE). Positive or negative bias in the model will have a greater impact on the RMSE method. Once this bias has been eliminated (calibration of the model), the RMSE and SE values should be equivalent.

The tendency of the magnitude of the forecast errors to increase (reduced precision) at greater measured ammonia concentrations was addressed by filtering the paired data used to develop the confidence intervals. Since ammonia concentrations in Salt Creek are not expected to exceed 5.0 mg/L, based on historic in-stream data under normal WWTP operating conditions, a subset of the paired data (measured versus predicted) was selected over the range of 0 to 5.5 mg/L.

Confidence intervals were computed based on the calibrated model (K=1.6 day^{-1}) and the subset of the paired data (measured values in the range 0 to 5.5 mg/l). With the reduction in the negative bias, the RMSE and the SE values are almost equivalent. In addition, the steps taken during the calibration process and the creation of the subset data have also decreased the magnitude of the confidence intervals. Since the results of the two methods are similar, and to take the most conservative approach (confidence intervals are slightly higher using the RMSE method), confidence intervals based on the RMSE were chosen and can be applied to the Salt Creek simulation values at each of the four sites. The results of both methods are presented in Table 3-4.

Table 3-4 Final Confidence Intervals and Regression (Based on k=1.6)

Regression Coefficients	Sites			
	SS3	BSS04	ISD	BSS08
Root Mean Square Error (RMSE)	1.17	0.79	0.88	0.96
Confidence Intervals (95%) (RMSE)	**±2.29**	**±1.55**	**±1.73**	**±1.88**
Standard Error (SE)	1.07	0.79	0.85	0.97
Confidence Intervals (95%) (SE)	±2.10	±1.55	±1.67	±1.91

2.8 Simulation of 30-Day Average Ammonia Concentrations

As initially discussed, one of the primary purposes of simulation modeling was to evaluate the ammonia exposure regime in Salt Creek prior to each bio-assessment (11 total) conducted from 1994 through 1999. The chronic exposure regime is expressed as a 30-day averaging period to match the current chronic exposure period as defined by the Environmental Protection Agency for ammonia. Predicted ammonia concentrations were evaluated for various exposure regimes including 30, 60, 90 and 180 days (approximately 6 months) prior to each bio-assessment. Maximum 30-day average ammonia concentrations were calculated for each exposure regime to evaluate the highest chronic ammonia exposure period experienced by the Salt Creek biological community. As discussed in Manuscript 1, the 180-day exposure regime was found to have the best correlation with a biological response under summer conditions. The maximum 30-day average ammonia concentrations for the 180-day period prior to each bio-assessment are shown in Table 3-5. For comparison purposes, the average ammonia concentration for the 30-days prior to each bio-assessment are shown in Table 3-6.

Table 3-5 Maximum 30-day Average Ammonia Concentrations 180-day Prior to Each Bio-assessment

Bio-assessment Start Date	Max 30-day Average Ammonia Concentration (mg/L) and Period of Occurrence by Site			
	Site BSS04, mg/L	Date of Occurrence	Site BSS08, mg/L	Date of Occurrence
8/29/94	1.29	3/8/94 - 4/6/94	1.83	3/9/94 - 4/7/94
12/19/94	2.10	11/10/94 - 12/9/94	2.87	10/20/94 - 11/18/94
2/20/95	1.64	11/10/94 - 12/9/94	2.27	10/20/94 - 11/18/94
8/21/95	3.76	2/23/95 - 3/24/95	5.62	2/23/95 - 3/24/95
3/4/96	4.72	11/7/95 - 12/6/95	5.35	11/14/95 - 12/13/95
9/13/96	3.46	3/19/96 - 4/17/96	2.99	3/19/96 - 4/17/96
3/5/97	1.26	10/16/96 - 11/14/96	2.13	1/14/97 - 2/12/97
8/29/97	4.84	3/3/97 - 4/1/97	5.32	3/12/97 - 4/10/97
8/16/98	3.41	2/19/98 - 3/20/98	4.04	2/19/98 - 3/20/98
2/1/99	3.42	11/24/98 - 12/23/98	3.23	1/2/99 - 1/31/99
8/24/99	2.92	3/4/99 - 4/2/99	3.21	3/4/99 - 4/2/99

Note: k = 1.6 day^{-1}

Table 3-6 Average Ammonia Concentrations 30-days Prior to Each Bio-assessment

Bio- Assessment Start Date	Average Ammonia Concentrations (mg/L) 30-days Prior to Bio-assessment by Site	
	Site BSS04, mg/L	Site BSS08, mg/L
8/29/94	0.48	0.73
12/19/94	2.10	2.87
2/20/95	1.73	2.45
8/21/95	0.53	1.52
3/4/96	3.44	4.53
9/13/96	1.59	1.10
3/5/97	1.84	2.98
8/29/97	1.25	2.04
8/16/98	1.21	0.83
2/1/99	3.06	3.23
8/24/99	2.28	1.33

Note: $k = 1.6\ day^{-1}$

2.9 Confidence Intervals for 30-day Average Ammonia Values

Confidence intervals around the 30-day average ammonia concentrations prior to each bio-assessment are the same as those developed for the predicted daily values, as discussed above and shown in Table 3-4. This approach assumes that the error distribution for the simulation model's daily predictions is equal to that for 30-day average predictions shown in Table 3-5 and Table 3-6.

3.0 PREDICTION OF FUTURE SALT CREEK AMMONIA CONCENTRATIONS FOR COMPLIANCE PURPOSES

The second function of either the simulation model or the regression modeling method is to allow the City to predict future Salt Creek ammonia concentrations and support in-stream compliance monitoring. As discussed in Manuscript 5 on Data Integration, the City proposes the use of Salt Creek in-stream monitoring for compliance with the site-specific chronic ammonia criteria for summer and winter. This will require the City to monitor ammonia daily in Salt Creek, as well as the final effluent. While the City will complete daily Salt Creek monitoring, the simulation model or regression model provides the City a predictive tool to evaluate future Salt Creek ammonia conditions. Predicting potential future conditions is important to the City, especially during periods of changing Salt Creek flows or seasonal transition periods (winter-to-summer and summer-to-winter), which can effect the treatability of ammonia in either WWTP, or the combination of both.

3.1 Simulation Modeling

Table 3-7 shows an annotated example of the simulation program in which Salt Creek ammonia concentrations can be predicted based on the required input factors. This method can be used to assess allowable WWTP discharge ammonia concentrations, based on a target in-stream ammonia value (criteria). To calculate both summer and winter ammonia concentrations, which utilize an ammonia loss term, seasonal pH and temperature and travel time would need to be applied. The example shown in Table 3-7 would use a set temperature, pH and travel time based on a critical summer month of August and critical winter month of January from City site-specific HydroLab® data collected in 1994 and 1995.

3.2 Regression Modeling

The relative large data set for concurrent in-stream and treatment plant total ammonia testing that was generated during *in situ* testing work from September 21, 1999 through October 20, 1999 suggests that multivariate regression should at least be investigated for possible use for comparative modeling against the simulation model discussed above. Data used in the regression model were collected during the *in situ* studies (30-days) and included: Site SS3 (North 27th St.) data collected twice per day (grab samples); Theresa Street and Northeast WWTP effluent collected at 4-hour intervals; and Site G (below North 84th St.) with discreet samples taken at 4-hour intervals.

The purpose of the regression modeling is twofold: (1) Provide a cross check to the more comprehensive simulation modeling which includes simple mass balance and ammonia loss; and (2) Evaluate its potential as an easier, more maintainable method and tool for treatment plant operators and management staff for future regulatory compliance efforts. Therefore, the purpose of the regression modeling summarized herein is not intended to replace the simulation modeling approach for establishing biological "endpoints" for site-specific ammonia criteria. Such regression (probabilistic) modeling does, however, offer a potential means of providing a convenient alternate approach to treatment plant effluent performance tracking.

The basic premise of any regression modeling is that the input variables are historically repeatable relative to themselves and that they reasonably capture the majority of the data ranges to be expected for a valid output prediction. This implies that, as the data set continues to grow over time with additional data collection efforts, one must presume that the accuracy of the prediction will continue to improve, provided that the data are collected in a consistent manner and that WWTP operations remain similar.

For the case in point, the input variables used were simply a combination of flow and total ammonia without any allowances for time of travel and ammonia loss; thus greatly simplifying the modeling approach. The presumption for this type of modeling is that the actual in-stream ammonia values reflect a repeatable pattern relative to upstream conditions as long as a consistent basis of comparison is used and, secondly, that the in-stream dilution is normally a much more significant mechanism than is the actual in-stream ammonia loss for the relatively short distances involved.

Table 3-7. Example of Simulation Model Setup for Salt Creek Ammonia or WWTP Effluent Ammonia Predictions

Season*	Above Theresa Street WWTP		Theresa Street		Mixed Conditions Below Theresa (Compliance Point)	Loss between SS3 and ISD			Upstream of Northeast Plant		Northeast WWTP		Mixed Conditions Below Northeast (Compliance Point)
	Backgrnd NH3 Conc. (mg/L)	Backgrnd Flow (cfs)	Flow (cfs)	NH3 Conc (mg/L)	Ammonia (mg/L)	Velocity (fps)	Time (days)	Loss Constant (K)	Backgrnd NH3 Conc. (mg/L)	Backgrnd Flow (cfs)	Flow (cfs)	NH3 Conc (mg/L)	Ammonia (mg/L)
Summer	Default or Other	Actual Value	Actual Value	Input or Calculated	Input or Calculated	Dependent on Flow Rate	Dependent on Flow Rate	Dependent on Flow and Temp	Calculated By Model	Actual Value	Actual Value	Input or Calculated	Input or Calculated
Winter	Default or Other	Actual Value	Actual Value	Input or Calculated	Input or Calculated	Dependent on Flow Rate	Dependent on Flow Rate	Dependent on Flow and Temp	Calculated By Model	Actual Value	Actual Value	Input or Calculated	Input or Calculated

* Summer: Temperature = 25.5 Celsius; pH = 8.1 s.u.
Winter: Temperature = 3.8 Celsius; pH = 7.8 s.u.

Figure 3-15 below shows the regression modeling results for total ammonia in Salt Creek for the stream reach from the Theresa St. Treatment Plant to Site SS3 at North 27th Street, which is near the end of the chronic mixing zone. Similarly, Figure 3-16 shows the regression modeling results for Site ISG, near the end of the chronic mixing zone for the Northeast WWTP. The latter regression is intended to mimic the entire stream reach from the Theresa Street WWTP to below the Northeast WWTP as a dynamic combined "system". For modeling convenience and future applicability, the data set for Figure 3-16 was converted to 24-hour averages. The data set for Figure 3-15 had to remain consistent with the grab samples taken at Site 3, but future data collection efforts for both end-of-chronic mixing zone sites would be geared toward 24-hour composite sampling.

Both of these regression models were used to estimate 30-day antecedent total ammonia conditions for the various bio-assessment events. It is realized that the data ranges from the source data (during the *in situ* event) for the input variables were slightly different than that of the various bio-assessment events, so some data extrapolation is inherent in the estimates. Nonetheless, the regression models appear to provide a reasonable cross check to the simulation model method discussed above, and the general regression modeling approach should be of benefit for future operational controls.

Figure 3-15. Regression Modeling Results for Salt Creek Sample Site SS3

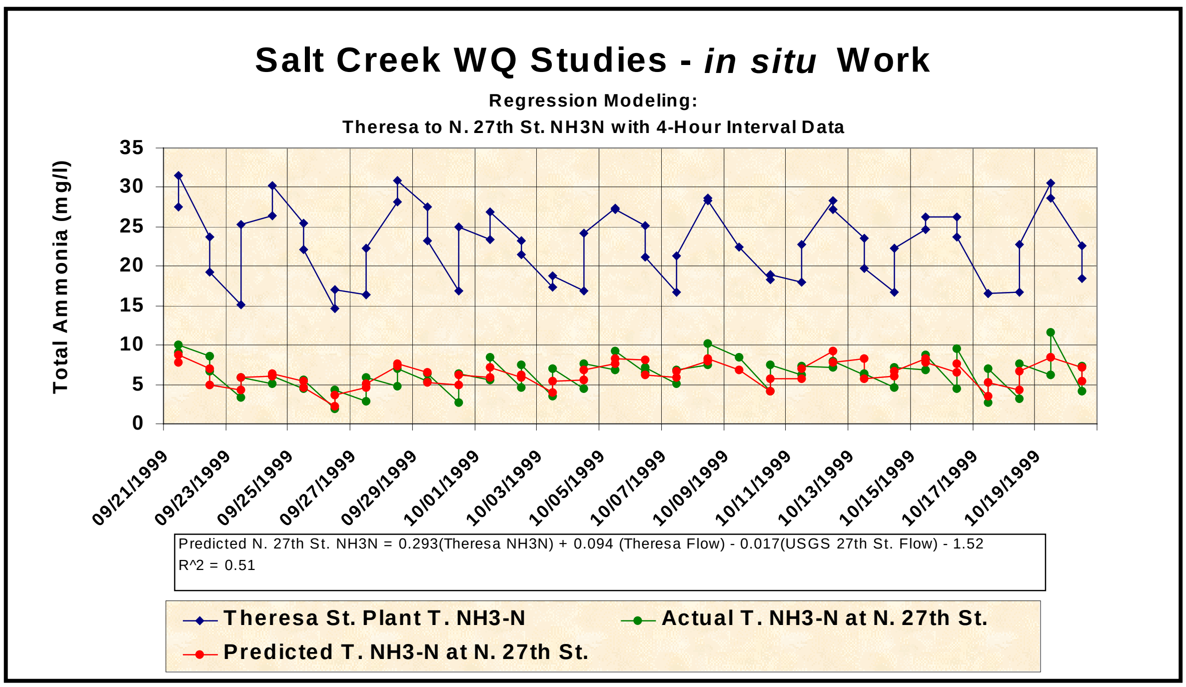
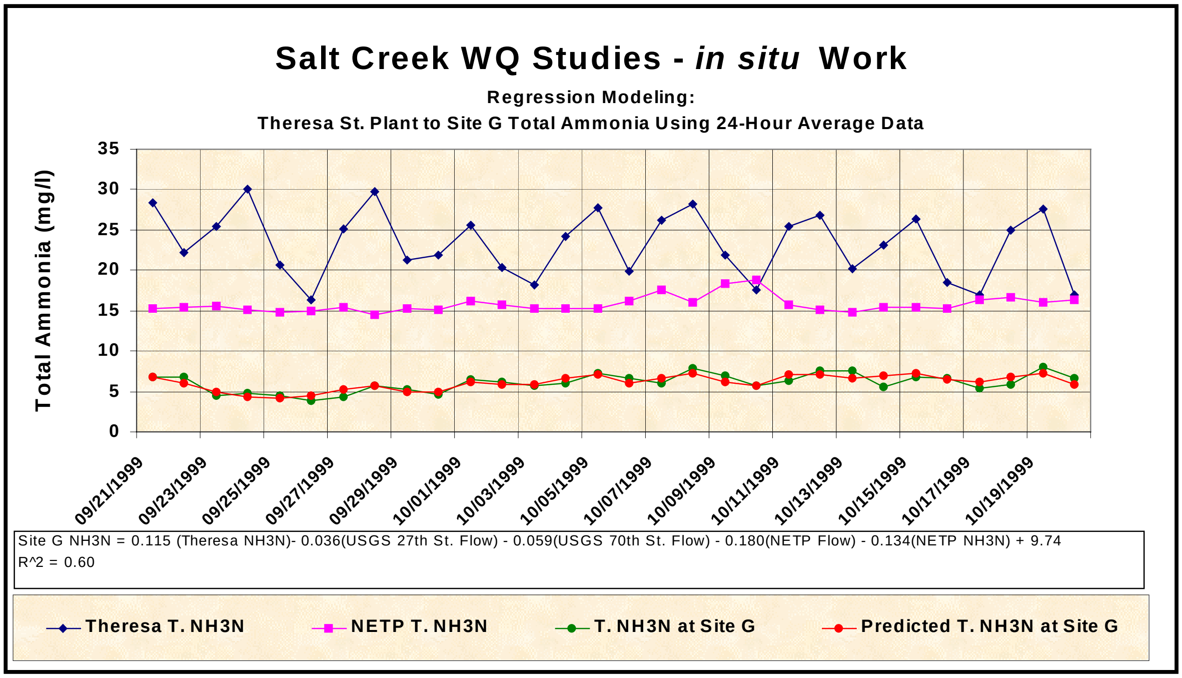


Figure 3-16. Regression Modeling Results for Salt Creek Sample Site ISG



<u>Electronic Version</u>: **<u>Go to Manuscript 4</u> – Supplemental Laboratory Testing and Quality Assurance/Quality Control (next manuscript)**

<u>Return to Start of Report</u> (for Table of Contents)

<u>Links to Supporting Data Files</u>

Attachment 3-A

Summary of Measured and Predicted Ammonia Concentrations (k=1.6 day^{-1})

Date	Predicted below Theresa	Measured below Theresa	Below Theresa Difference	Predicted at BSSO4	Measured at BSSO4	BSSO4 Difference	Predicted Above Northeast	Measured above Northeast	Above Northeast difference	Predicted Below Northeast	Measured below northeast	Below Northeast Difference
6/28/94	0.33	0.76	-0.43	0.30	0.24	0.06	0.20	0.05	0.15	0.40	0.67	-0.27
7/12/94	0.50	0.05	0.45	0.44	0.12	0.32	0.27	0.05	0.22	0.62	0.52	0.10
7/26/94	0.29	0.68	-0.39	0.25	0.58	-0.33	0.15	0.26	-0.11	0.49	0.14	0.35
8/9/94	0.22	0.43	-0.21	0.19	0.47	-0.28	0.13	0.36	-0.23	0.45	0.62	-0.17
8/23/94	1.80	1.90	-0.10	1.56	1.80	-0.24	0.93	1.00	-0.07	1.56	1.30	0.26
8/29/94	1.63	1.20	0.43	1.43	1.20	0.23	0.89	0.67	0.22	1.52	0.57	0.95
9/5/94	0.39	0.61	-0.22	0.36	0.43	-0.07	0.29	0.51	-0.22	0.58	0.84	-0.26
9/13/94	1.39	1.40	-0.01	1.29	1.40	-0.11	0.97	0.66	0.31	1.71	1.70	0.01
9/14/94	1.78	1.80	-0.02	1.64	1.60	0.04	1.22	0.80	0.42	1.86	1.20	0.66
9/15/94	2.12	0.05	2.07	1.95	2.40	-0.45	1.42	1.60	-0.18	1.96	2.10	-0.14
9/16/94	1.96	0.73	1.23	1.79	2.10	-0.31	1.29	1.00	0.29	2.00	2.00	0.00
9/20/94	1.00	3.00	-2.00	0.93	2.50	-1.57	0.71	0.92	-0.21	0.98	2.10	-1.12
10/5/94	2.03	2.10	-0.07	1.94	1.80	0.14	1.64	1.10	0.54	2.38	1.30	1.08
10/13/94	2.37	4.20	-1.83	2.24	3.30	-1.06	1.82	2.30	-0.48	3.13	3.60	-0.47
11/8/94	1.37	1.80	-0.43	1.34	1.70	-0.36	1.24	1.10	0.14	2.17	2.10	0.07
12/13/94	2.11	0.20	1.91	2.08	2.30	-0.22	1.98	2.20	-0.22	2.93	3.60	-0.67
1/10/95	1.97	2.00	-0.03	1.94	2.70	-0.76	1.85	0.27	1.58	2.78	0.27	2.51
1/24/95	2.91	1.60	1.31	2.88	1.70	1.18	2.74	1.20	1.54	3.16	3.30	-0.14
2/6/95	1.70	0.70	1.00	1.68	0.69	0.99	1.61	0.81	0.80	2.00	1.20	0.80
2/28/95	2.63	3.30	-0.67	2.59	3.60	-1.01	2.47	2.90	-0.43	3.22	4.40	-1.18
3/14/95	1.16	1.30	-0.14	1.14	1.90	-0.76	1.07	0.94	0.13	1.33	1.20	0.13
4/19/95	0.69	0.38	0.31	0.66	0.61	0.05	0.58	0.50	0.08	1.10	1.10	0.00
7/5/95	0.18	0.38	-0.20	0.16	1.60	-1.44	0.10	0.50	-0.40	0.27	1.20	-0.93
7/27/95	0.30	0.39	-0.09	0.26	0.32	-0.06	0.14	0.05	0.09	1.42	1.80	-0.38
8/3/95	1.50	0.67	0.83	1.31	0.56	0.75	0.78	0.32	0.46	2.04	1.90	0.14
8/21/95	0.69	0.43	0.26	0.60	0.19	0.41	0.35	0.28	0.07	1.69	1.00	0.69
3/13/96	6.66	7.00	-0.34				6.10	6.50	-0.40	6.87	6.70	0.17
9/13/96	2.97	3.30	-0.33	2.76	2.90	-0.14	2.11	1.80	0.31	1.98	1.60	0.38
3/5/97	1.10	0.89	0.21	1.08	0.95	0.13	1.02	0.73	0.29	1.74	1.40	0.34
8/18/97	2.27	0.28	1.99	1.96	0.29	1.67	1.15	0.01	1.14	2.32	1.08	1.24
8/29/97	3.24	2.30	0.94	2.77	3.20	-0.43	1.57	1.80	-0.23	2.63	4.00	-1.37
8/17/98	1.97	0.40	1.57	1.74	0.35	1.39	1.10	0.05	1.05	1.22	0.20	1.02
2/1/99	3.44	1.92	1.52	3.39	2.07	1.32	3.23	1.79	1.44	3.55	1.98	1.57
8/23/99	2.55	4.05	-1.50	2.26	3.71	-1.45	1.46	3.83	-2.37	1.39	3.02	-1.63
9/21/99	7.91	9.54	-1.63				5.32	6.31	-1.00	5.97	6.85	-0.88
9/22/99	5.79	7.65	-1.86				3.92	8.52	-4.60	4.66	6.79	-2.13
9/23/99	4.35	4.61	-0.26				3.13	3.41	-0.28	3.66	4.55	-0.89
9/24/99	3.86	5.53	-1.67				2.83	3.81	-0.98	3.20	4.73	-1.54
9/25/99	2.95	4.95	-2.00				2.14	3.42	-1.28	2.59	4.40	-1.82
9/26/99	2.76	3.13	-0.36				1.97	2.53	-0.56	2.58	3.84	-1.27
9/27/99	4.41	4.38	0.03				3.14	3.43	-0.29	3.70	4.35	-0.65
9/28/99	5.05	5.87	-0.82				3.62	4.68	-1.05	4.02	5.72	-1.70
9/29/99	3.85	5.86	-2.01				2.74	4.02	-1.27	3.34	5.19	-1.86
9/30/99	4.16	4.52	-0.36				2.96	3.46	-0.51	3.55	4.60	-1.04
10/1/99	6.09	6.97	-0.88				4.94	5.42	-0.48	5.67	6.43	-0.76
10/2/99	5.20	6.02	-0.82				4.19	5.23	-1.05	4.99	6.24	-1.26
10/3/99	4.93	5.19	-0.26				3.94	4.60	-0.66	4.80	5.75	-0.95

Date	Predicted below Theresa	Measured below Theresa	Below Theresa Difference	Predicted at BSSO4	Measured at BSSO4	BSSO4 Difference	Predicted Above Northeast	Measured above Northeast	Above Northeast difference	Predicted Below Northeast	Measured below northeast	Below Northeast Difference
10/4/99	7.71	6.03	1.69				6.11	5.46	0.65	6.84	5.97	0.87
10/5/99	8.74	8.02	0.72				6.94	6.92	0.02	7.52	7.31	0.21
10/6/99	6.36	6.83	-0.47				5.04	5.80	-0.76	5.96	6.68	-0.72
10/7/99	8.79	5.89	2.90				6.96	5.91	1.06	7.74	5.97	1.77
10/8/99	9.53	8.88	0.65				7.53	6.29	1.24	8.08	7.90	0.18
10/9/99	7.22	8.41	-1.19				5.70	5.86	-0.16	6.72	6.97	-0.26
10/10/99	5.68	5.78	-0.11				4.48	4.35	0.13	5.71	5.64	0.07
10/11/99	9.06	6.76	2.30				7.11	5.46	1.65	7.74	6.26	1.48
10/12/99	9.53	7.55	1.98				7.49	6.81	0.68	8.05	7.57	0.48
10/13/99	7.48	6.24	1.24				5.84	5.10	0.74	6.55	7.50	-0.95
10/14/99	9.32	5.91	3.41				7.22	5.09	2.13	7.86	5.50	2.36
10/15/99	10.24	7.85	2.39				7.94	6.49	1.46	8.48	6.77	1.71
10/16/99	6.97	7.05	-0.08				5.39	5.80	-0.42	6.22	6.68	-0.46
10/17/99	6.23	4.88	1.34				4.82	4.08	0.74	5.86	5.40	0.46
10/18/99	9.40	5.41	3.99				7.29	4.94	2.35	8.02	5.80	2.22
10/19/99	10.43	8.92	1.51				8.09	7.40	0.69	8.63	8.09	0.54
10/20/99	6.06	5.79	0.27				4.74	5.46	-0.72	5.72	6.67	-0.94

Attachment 3-B

Summary Of Measured And Predicted Ammonia Concentrations Used To Develop Confidence Intervals (k=1.6 day^{-1})

Date	Predicted below Theresa	Measured below Theresa	Below Theresa Difference	Predicted at BSSO4	Measured at BSSO4	BSSO4 Difference	Predicted Above Northeast	Measured above Northeast	Above Northeast difference	Predicted Below Northeast	Measured below northeast	Below Northeast Difference
6/28/94	0.33	0.76	-0.43	0.30	0.24	0.06	0.20	0.05	0.15	0.40	0.67	-0.27
7/12/94	0.50	0.05	0.45	0.44	0.12	0.32	0.27	0.05	0.22	0.62	0.52	0.10
7/26/94	0.29	0.68	-0.39	0.25	0.58	-0.33	0.15	0.26	-0.11	0.49	0.14	0.35
8/9/94	0.22	0.43	-0.21	0.19	0.47	-0.28	0.13	0.36	-0.23	0.45	0.62	-0.17
8/23/94	1.80	1.90	-0.10	1.56	1.80	-0.24	0.93	1.00	-0.07	1.56	1.30	0.26
8/29/94	1.63	1.20	0.43	1.43	1.20	0.23	0.89	0.67	0.22	1.52	0.57	0.95
9/5/94	0.39	0.61	-0.22	0.36	0.43	-0.07	0.29	0.51	-0.22	0.58	0.84	-0.26
9/13/94	1.39	1.40	-0.01	1.29	1.40	-0.11	0.97	0.66	0.31	1.71	1.70	0.01
9/14/94	1.78	1.80	-0.02	1.64	1.60	0.04	1.22	0.80	0.42	1.86	1.20	0.66
9/15/94	2.12	0.05	2.07	1.95	2.40	-0.45	1.42	1.60	-0.18	1.96	2.10	-0.14
9/16/94	1.96	0.73	1.23	1.79	2.10	-0.31	1.29	1.00	0.29	2.00	2.00	0.00
9/20/94	1.00	3.00	-2.00	0.93	2.50	-1.57	0.71	0.92	-0.21	0.98	2.10	-1.12
10/5/94	2.03	2.10	-0.07	1.94	1.80	0.14	1.64	1.10	0.54	2.38	1.30	1.08
10/13/94	2.37	4.20	-1.83	2.24	3.30	-1.06	1.82	2.30	-0.48	3.13	3.60	-0.47
11/8/94	1.37	1.80	-0.43	1.34	1.70	-0.36	1.24	1.10	0.14	2.17	2.10	0.07
12/13/94	2.11	0.20	1.91	2.08	2.30	-0.22	1.98	2.20	-0.22	2.93	3.60	-0.67
1/10/95	1.97	2.00	-0.03	1.94	2.70	-0.76	1.85	0.27	1.58	2.78	0.27	2.51
1/24/95	2.91	1.60	1.31	2.88	1.70	1.18	2.74	1.20	1.54	3.16	3.30	-0.14
2/6/95	1.70	0.70	1.00	1.68	0.69	0.99	1.61	0.81	0.80	2.00	1.20	0.80
2/28/95	2.63	3.30	-0.67	2.59	3.60	-1.01	2.47	2.90	-0.43	3.22	4.40	-1.18
3/14/95	1.16	1.30	-0.14	1.14	1.90	-0.76	1.07	0.94	0.13	1.33	1.20	0.13
4/19/95	0.69	0.38	0.31	0.66	0.61	0.05	0.58	0.50	0.08	1.10	1.10	0.00
7/5/95	0.18	0.38	-0.20	0.16	1.60	-1.44	0.10	0.50	-0.40	0.27	1.20	-0.93
7/27/95	0.30	0.39	-0.09	0.26	0.32	-0.06	0.14	0.05	0.09	1.42	1.80	-0.38
8/3/95	1.50	0.67	0.83	1.31	0.56	0.75	0.78	0.32	0.46	2.04	1.90	0.14
8/21/95	0.69	0.43	0.26	0.60	0.19	0.41	0.35	0.28	0.07	1.69	1.00	0.69
3/13/96				0.00	0.00							
9/13/96	2.97	3.30	-0.33	2.76	2.90	-0.14	2.11	1.80	0.31	1.98	1.60	0.38
3/5/97	1.10	0.89	0.21	1.08	0.95	0.13	1.02	0.73	0.29	1.74	1.40	0.34
8/18/97	2.27	0.28	1.99	1.96	0.29	1.67	1.15	0.01	1.14	2.32	1.08	1.24
8/29/97	3.24	2.30	0.94	2.77	3.20	-0.43	1.57	1.80	-0.23	2.63	4.00	-1.37
8/17/98	1.97	0.40	1.57	1.74	0.35	1.39	1.10	0.05	1.05	1.22	0.20	1.02
2/1/99	3.44	1.92	1.52	3.39	2.07	1.32	3.23	1.79	1.44	3.55	1.98	1.57
8/23/99	2.55	4.05	-1.50	2.26	3.71	-1.45	1.46	3.83	-2.37	1.39	3.02	-1.63
9/21/99												
9/22/99												
9/23/99	4.35	4.61	-0.26				3.13	3.41	-0.28	3.66	4.55	-0.89
9/24/99							2.83	3.81	-0.98	3.20	4.73	-1.54
9/25/99	2.95	4.95	-2.00				2.14	3.42	-1.28	2.59	4.40	-1.82
9/26/99	2.76	3.13	-0.36				1.97	2.53	-0.56	2.58	3.84	-1.27
9/27/99	4.41	4.38	0.03				3.14	3.43	-0.29	3.70	4.35	-0.65
9/28/99							3.62	4.68	-1.05			
9/29/99							2.74	4.02	-1.27	3.34	5.19	-1.86
9/30/99	4.16	4.52	-0.36				2.96	3.46	-0.51	3.55	4.60	-1.04
10/1/99							4.94	5.42	-0.48			

Date	Predicted below Theresa	Measured below Theresa	Below Theresa Difference	Predicted at BSSO4	Measured at BSSO4	BSSO4 Difference	Predicted Above Northeast	Measured above Northeast	Above Northeast difference	Predicted Below Northeast	Measured below northeast	Below Northeast Difference
10/2/99							4.19	5.23	-1.05			
10/3/99	4.93	5.19	-0.26				3.94	4.60	-0.66			
10/4/99							6.11	5.46	0.65			
10/5/99												
10/6/99												
10/7/99												
10/8/99												
10/9/99												
10/10/99							4.48	4.35	0.13			
10/11/99							7.11	5.46	1.65			
10/12/99												
10/13/99							5.84	5.10	0.74			
10/14/99							7.22	5.09	2.13			
10/15/99												
10/16/99												
10/17/99	6.23	4.88	1.34				4.82	4.08	0.74	5.86	5.40	0.46
10/18/99	9.40	5.41	3.99				7.29	4.94	2.35			
10/19/99												
10/20/99							4.74	5.46	-0.72			